Supplemental Biological Evaluation of Hemlock Woolly Adelgid Along Rollock Road, Flight 93 National Memorial, Somerset County, Pennsylvania

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Abstract

In mid-June, 2014 personnel from the USDA Forest Service, Northeastern Area, Forest Health Protection, Morgantown, WV. Field Office conducted a survey to evaluate hemlock woolly adelgid (HWA), *Adelges tsugae* Annand (Hemiptera: Adelgidae), population densities along the family entrance (Rollock Road), at the Flight 93 National Memorial in southwestern Pennsylvania. The purpose of the survey was to assess the need for treatment of hemlock trees within view of Rollock Road at the memorial. Hemlock woolly adelgid is present throughout the survey areas at high levels. It is recommended that this area be included with the hemlock grove and that and a chemical suppression/prevention treatment plan be put into place to protect eastern hemlock trees. The release of predatory beetles is also recommended as part of an integrated control strategy for HWA.

Purpose and Need

The Morgantown Field Office (Mumford and Norton) received a request for a site visit from Keith Newlin, Deputy Superintendent of the Western Pennsylvania Parks, National Park Service to access hemlock woolly adelgid activity along Rollock Road at Flight 93 memorial family entrance. This project was undertaken by the MFO to address this request and to identify any significant issues that might occur as a result of hemlock woolly adelgid within the family entrance area at the Flight 93 memorial.

Project Location/Description

The Flight 93 National Memorial is located in southwestern Pennsylvania in Somerset county (40º04'N, -78º53'W). The Memorial covers approximately 2,200 acres of which 1,025 acres are forested (Figure 1). The Memorial lies in the Appalachian mixed hardwood region (Rhoads and Block, 2005) within the oak-hickory ecological forest type, which is associated with oaks (*Quercus*) yellow popular (*Liriodendron tulipifera* L.) and northern hardwood forest cover type (Smith et al. 1983). The site has been extensively modified by human activity related to the mining of bituminous coal (USDI, 2007).

Rollock road is located near the southern end of the memorial, and contains a comfort station and several plantings. This area covers approximately 25 acres of which 8.5 acres are forested (Figure 2). Soils within the forested area of the family entrance road are classified as Brinkerton, Cavode silt lomes and Udorthents mine spoil (NRCS, 2012). The majority of soil in the area has poor drainage with topographic relief ranging from 0-25 percent and shallow water table (<18 inches; (NRCS, 2012).

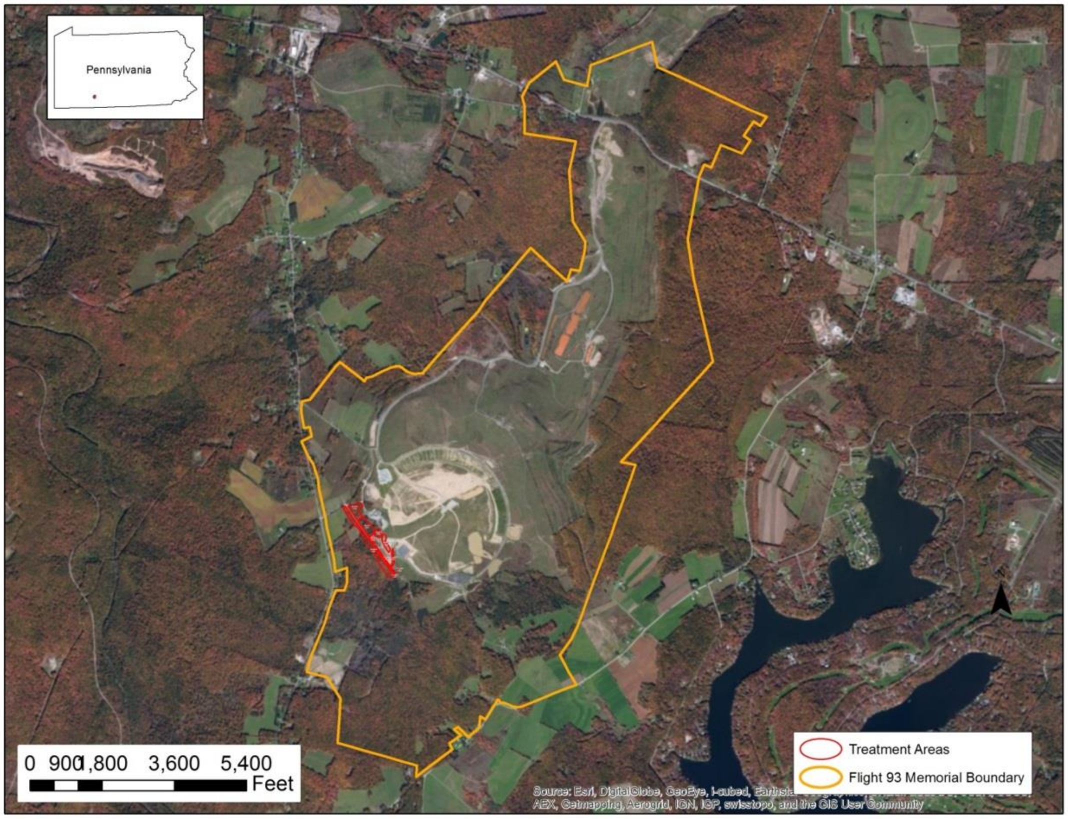

Figure 1. Flight 93 National Memorial, Somerset County, Pennsylvania.

Project Objectives

The objectives for this evaluation were to 1) assess the location of eastern hemlock (*Tsuga canadensis*) along the family entrance road 2) inventory the physical characteristics of the trees that are within sight from Rollock Road 3) evaluate the extent and impact of hemlock woolly adelgid, and 4) determine the need for management activities along the family entrance, Rollock Road at the Flight 93 National Memorial.

Project Methods

ARCMAP data

We used ARCMAP® data provide by U.S. Department of the Interior, National Park Service to identify the administrative boundary area and crash site. These boundary areas were then overlaid with National Agricultural Imagery Program (NAIP) data and Google earth imagery, which was used to digitize tree cover, calculate acreage, and identify tree positions.

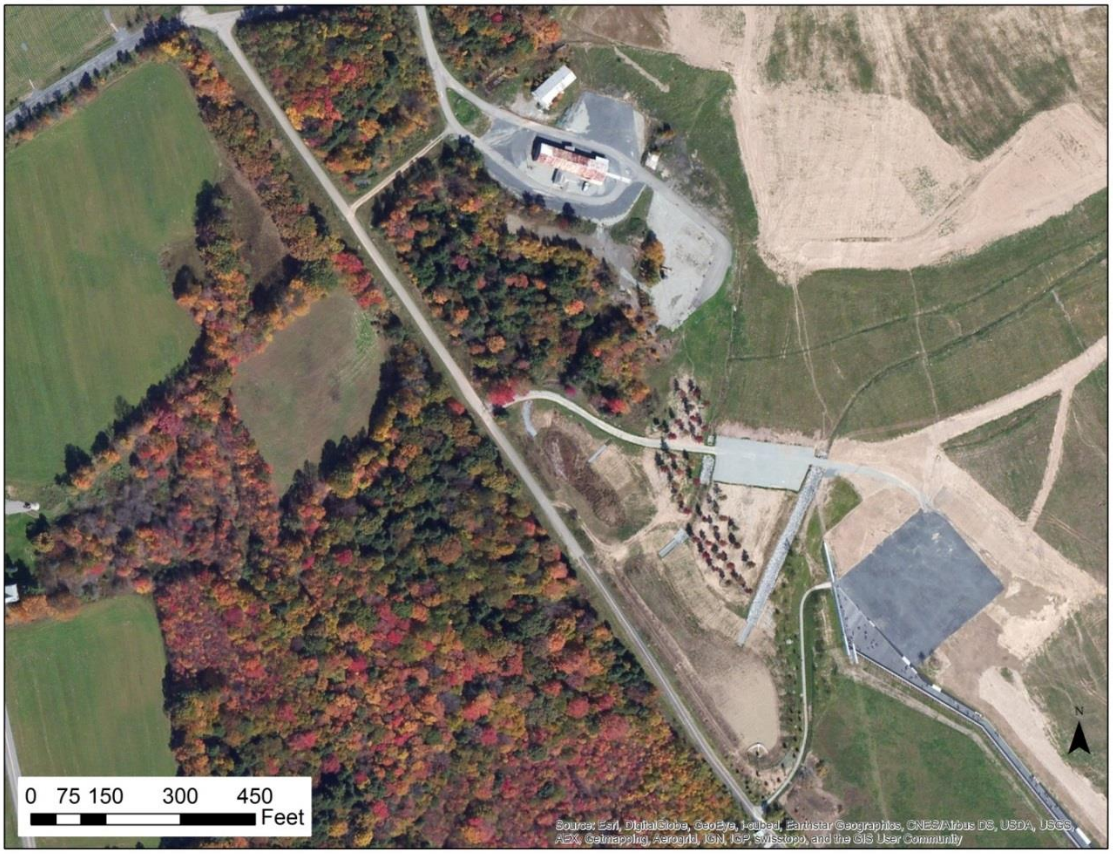

Figure 2. Flight 93 National Memorial crash site family entrance, Rollock Road, Somerset County, Pennsylvania.

Inventory areas and tree assessment
To inventory and assess HWA populations along Rollock Road we divided the area into four blocks (Cristofori et al.), using the road and connecting roads to divide up the area (Figure 3). Within each block all hemlock trees located within 50 feet of the tree line were inventoried. Tree data was collected on all trees at least 3.0 inches in diameter at breast height (dbh; 4.5 ft. above the ground; USDA 2001) within each block. For each tree (≥ 3.0 inches dbh) we recorded crown class (i.e. dominant, co-dominant, intermediate, and overtopped; USDA 2001), visible tree damage (e.g. conks, cankers, wounds, cracks, etc.), dbh, indications of HWA infestation, presence of new growth, and whether the tree was visible from Rollock Road. Each hemlock was tagged with a unique number using blue aluminum tags and aluminum roofing nails. GPS coordinates were also taken of each tree using a handheld Trimble GPS device and mapped using ArcGIS.

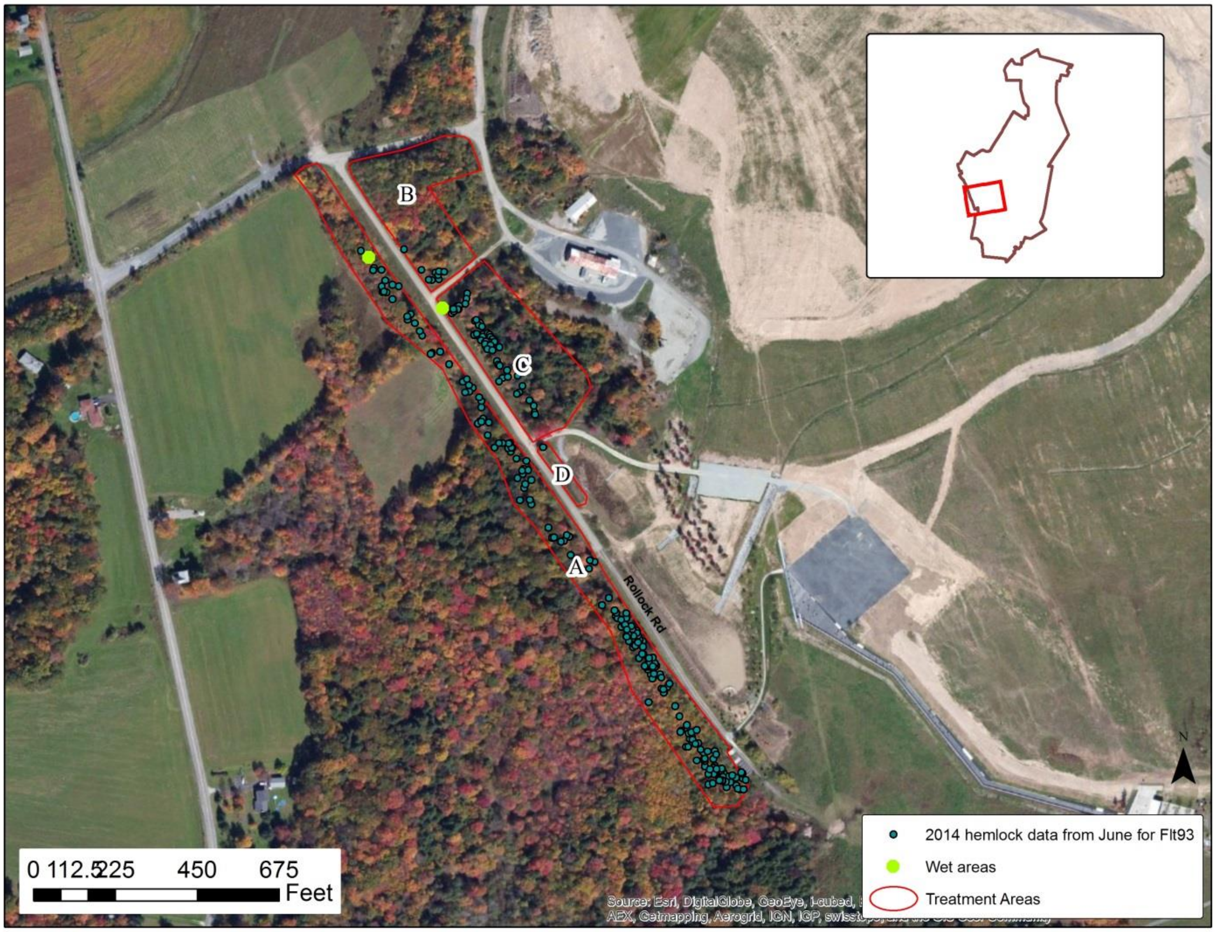

Figure 3. Rollock road and survey block locations, Flight 93 National Memorial, Somerset County, Pennsylvania.

Results

In the four blocks along Rollock Road, 266 hemlock trees were tagged, measured and assessed. Trees ranged in size from 3 to 33 inches dbh, with an average size of 10.1 ± 5.5 inches (Table 1). Ninety-eight percent of the trees examined had signs of HWA present. Two-hundred and fourteen hemlock trees were visible from Rollock Road, of which 17 had significant tree damage (Table 2). Only two percent of the hemlocks survey areas were found to be dead (Table 1.). More than half of the hemlock trees surveyed were in the understory (Table 2.) of these mixed hardwood forest type composed of red maple (*Acer rubrum*), black cherry (*Prunus serotina)*, black birch (*Betula lenta*), northern red oak (*Quercus rubra*), yellow birch (*Betula alleghaniensis*), ash, (Fraxinus spp.), sugar maple (*Acer saccharum*). Shrub species present included rosebud rhododendron (*Rhododendron maximum*), greenbrier (*Smilax sp*.) and poison ivy (toxicodendron radicans). Herbaceous species such as fern and sedges (Carex spp.) were also observed.

Table 1.Sum of Acres, number of alive and dead hemlock, average dbh, standard deviation of dbh and sum of dbh for survey blocks along the Rollock Road family entrance, Flight 93 National Memorial, Somerset County, Pennsylvania**.**

Block	Acres	Number of Alive Hemlock	Number of Dead Hemlock	Average dbh*	StdDev of dbh	Sum of dbh
A	4.2	201	0	10.59	5.81	2127.80
B	1.9	9	2	11.64	4.65	104.80
C	2.2	55	3	8.04	3.61	442.10
E	0.2	1	0	13.80		13.80
Total	**8.5**	**266**	**5**	**10.11**	**5.48**	**2688.50**

* diameter at breast height (dbh; 4.5 ft. above the ground)

Table 2. Number and crown positon of eastern hemlock visible from Rollock Road by survey block, Flight 93 National Memorial, Somerset County, Pennsylvania.

Block	Visible from Rollock Road		Crown Position of Visible Trees			
	Yes	**No**	**Dominant**	**Co-dominant**	**Intermediate**	**Overtopped**
A	149	52	29	31	73	64
B	9	0	4	4	1	1
C	55	0	16	16	22	4
E	1	0	1	0	0	0
Total	**214**	**52**	**52**	**49**	**96**	**69**

Project Discussion

The main objectives for this evaluation is to determine the extent and impact of hemlock woolly adelgid, inventory the area, and evaluate the need for management activities along Rollock Road at the family entrance area of the Flight 93 National Memorial. Nearly all the hemlock trees in the survey blocks have HWA present.   Fortunately, no wide-scale mortality or decline was detected in the trees surveyed.

Currently, the only available options for protecting eastern hemlock from HWA are individual tree chemical treatments. Treatments are limited by the biology and feeding behavior of HWA, its population densities, the site conditions (i.e. proximity to streams), accessibility and the limited application technology currently available. Insecticide treatments are effective, although they are conducted on an individual tree basis and can be both labor intensive and costly. Thus treatment strategies are typically focused in high value sites such as recreational or scenic areas. Classical biological controls such as predators and pathogens are being pursued by the USDA Forest Service but will likely take years to become effectively established. As such, preservation of hemlocks at the family entrance will require intensive monitoring and an aggressive chemical

treatments strategy. Since HWA has been found within the area it is recommend that a comprehensive hemlock management plan be developed and a chemical suppression/prevention treatment plan be put into place as soon as possible.

Management Options

Three management options have been evaluated for managing HWA at the Flight 93 Memorial. The two intervention options are offered based on the following objectives: 1) protect all hemlock trees within the four blocks; and 2) protect hemlock but at a reduced density based on visibility from Rollock Road. Each option is discussed below.

No action option

In this option hemlock woolly adelgid is allowed to infest eastern hemlock trees along the family entrance. Should this option be selected, it is likely that all eastern hemlock trees would be attacked and die as a result of HWA feeding. This would result in the loss of hemlocks along the entrance road, result in a hazard to visiting family members, and a reduction in the overstory canopy. The majority of the seedlings and saplings on the area are green ash, red maple, and other hardwood species, therefore the no action option will likely result in the conversion of the area from a mixed eastern hemlock stand to a mixed hardwood stand.

Intervention Options

Foliar chemical treatments

Aerial spray using horticultural oil or insecticidal soap is not an option because aerial sprays could not provide the needed "saturation" necessary to ensure that the insecticide adequately covers the insect. Aerial spraying with more toxic insecticides (e.g. malathion or diazinon) would have very significant, unacceptable impacts on a wide range of non-target insects and other animals and limited control benefits (Evans 2000). Application of insecticides using ground spraying equipment is generally limited to areas accessible to hydraulic spray equipment and areas where over spray or runoff would not contaminate streams, lakes or ponds. Backpack sprayers could be effectively used for foliar treatment of infested seedlings and saplings to protect regeneration.

Systemic Insecticides

Several systemic insecticides labeled for adelgids can be injected (e.g. imidacloprid, dicrotophos), implanted (e.g. acephate) or sprayed on the bark (e.g. dinotefuran) or foliage of

hemlock trees. Imidacloprid is by far the most common systemic insecticide being used to control HWA and is applied as a soil drench, truck injection, foliar treatment or soil application. These insecticides are absorbed and trans-located by the vascular system of the tree to feeding adelgids and will effectively suppress HWA populations (Doccola et al. 2003, Webb et al. 2003, Evans 2000, Steward and Horner 1994, McClure 1992).

Biological insecticides

Twenty fungal genera and 79 entomopathogenic isolates associated with HWA have been found in the eastern United States and China (Reid et al. 2010). Of all the isolates collected, none were specialist on HWA (Havill et al. 2014). Several of the fungi recovered *Lecanicillium lecanii* (Ewers and Zimmermann), *Beauveria bassiana* (Balasamo) and *Isaria farinosa* (Holms.) are known insect pathogens with global distribution and showed high efficacy against HWA (Reid et al. 2010). Biological insecticides use against HWA is still in the early stages of development and evaluation and it will likely be several years before a commercial formulation becomes available.

Biological control

There are no known parasites of adelgids. There are three predatory beetles that have been released against the HWA in the east: *Sasajiscymnus tsugae* (Sasaji & McClure: Coleoptera: Coccinelidae), was released in 1995, *Laricobius nigrinus* Fender (Coleoptera: Derodontidae) in 2003, and *Scymnus sinuanodulus* (Yu & Yao; Coleoptera: Coccinelidae) in 2004. Each with its own unique dispersal habits, reproductive potential, feeding behavior, and suitable climate regimes. They are all fairly host specific. Releases are usually done in infested hemlock stands found along the leading edge, or in areas where hemlocks are still healthy and HWA densities have not yet overwhelmed the trees. Other beetles currently being evaluated are *Scymnus ningshanensis* (Yu & Yao; Coleoptera: Coccinelidae), *Scymnus coniferarum* (Crotch: Coleoptera: Coccinelidae), S*cymnus camptodromus* (Yu and Liu; Coleoptera: Coccinelidae) and *Laricobius osakensis* Mongomery and Shiyake (Coleoptera: Derodontidae) all of which show promise as biological control agents. The release and establishment of HWA natural enemies is not likely to provide any short term control of HWA. This long-term approach is still experimental and will likely require a complex of natural enemies to maintain HWA below damaging levels. It may be years before these predators can self-perpetuate sufficiently before any level of success can be determined.

Alternatives

With the previously described options in mind, the following alternatives are offered:

Alternative 1.	No action
Alternative 2.	The chemical treatment of all hemlock trees (up to limits on active ingredients per acre) within the blocks.
Alternative 3.	The chemical treatment and removal of selected understory and overstory hemlock trees to maintain a component of visible hemlock along the family entrance along Rollock Road.

Recommendations

Alternative three is recommended based on the following considerations.

1) The hemlock trees along the family entrance are currently infested with HWA. Trees will continue to die as a result of the HWA infestation. Reducing the number of hemlocks to those visible from Rollock Road will reduce tree density and increase the overall health of the stand and allow for selection of the best growing stock and promote the sustainability and visibility of the hemlock along the road.

2) Chemical treatments are recommended for HWA control on individual, hemlock trees visible from the road in each of the four blocks. Insecticides have been shown to be an effective treatment against the hemlock woolly adelgid and will allow for the retention of eastern hemlock.

3) Release and establishment of *Sasajiscymnus tsugae, Scymnus sinuanodulus,* and *Laricobius nigrinus* predatory beetles is also recommended in blocks on hemlocks that are not in close proximity to chemical treatments. The establishment of these natural enemies offers the opportunity for long-term control and may minimize the need for repeated chemical treatments in future years.

Species Evaluation

Hemlock Woolly Adelgid

The hemlock woolly adelgid is believed to have been introduced into the eastern United States from Japan (Havill and Foottit. 2007) sometime before 1951 on nursery stock. It was first discovered on eastern hemlock trees in a municipal park that had previously been a private estate (Souto et al. 1996, Ward et al. 2004). Over the next 30 years HWA slowly spread through the Mid-Atlantic States (Souto et al. 1996). By the late 1980s and 1990s HWA population had expanded rapidly and was reported to be causing widespread mortality (Cheah et al. 2004). HWA is currently established in 19 eastern States from Georgia to Maine.

Life Cycle

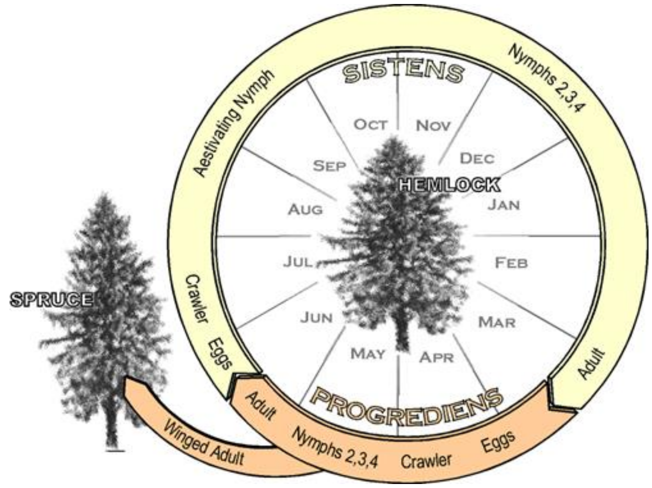

Figure 5. Life cycle of the hemlock woolly adelgid on hemlock in North America (Ward et al. 2004)

The hemlock woolly adelgid has a complex life cycle involving both sexual and asexual stages on both spruce and hemlock (figure 5; McClure 1989). The life cycle on eastern hemlock is bivoltine including a “sistens” or wingless winter generation that starts in late spring and lasts for 9 to 10 months (McClure 1989) and a “progrediens” or spring generation that starts in the early spring. The progredien generation is composed of both winged (sexuparae) and wingless offspring and lasts for about three months (Ward et al. 2004). The winged generation is the sexual migratory stage which leaves hemlock to find spruce (McClure 1987). The percentage of the population of progrediens is strongly density dependent; as the tree health declines and preferred feeding sites (new growth) is reduced the percentage of winged adults increases (McClure 1991). Because of the lack of a suitable primary host a spruce species (Tiger-tail spruce, *Picea torano* K. Koch) in the eastern United States the production of the winged form results in a substantial loss of individuals from the spring generation (McClure 1989, Havill et al. 2014). HWA has a high reproductive potential with each adult producing up to 300 eggs (McClure et al. 2001). The eggs hatch into first instar mobile crawlers, which are active for one to two days, before settling or being dispersed (McClure 1987, Ward et al. 2004). Once settled the nymph inserts its stylet and feeds on the xylem ray parenchyma cells at the base of the hemlock needles (Young et al. 1995). The adelgid then develops through four instars before becoming an adult (McClure 1989).

Feeding Impact

The combination of two annual generations, a high reproductive capacity, and the lack of natural enemies (Van Driesche et al. 1996, Wallace and Hain 1998, Cheah et al. 2004) gives HWA the ability to increase rapidly in numbers (McClure 1989). Feeding can quickly lead to needle loss, dieback and mortality (Cheah et al. 2004) and appears to induce a hypersensitive response in the tree (Radville et al., 2011). Although the exact physiological effect of HWA feeding on hemlock is not well understood, feeding by the adelgid, impacts the uptake and movement of water (McClure 1995, Domec et al., 2013), and reduces the trees energy reserves (Ward et al. 2004) which can lead to tree mortality in 4-7 years (Orwig and Foster 1998, McClure et al.

2001), although some trees can last more than 15 years (Souto et al. 1996, Paradis et al. 2008, Havill et al. 2014). Other stress factors such as weather, site conditions, stand overstocking, and defoliation, can intensify the impacts of HWA (Havill et al. 2014). All life stages of hemlock, from seedling to mature old-growth trees are fed upon (McClure 2001).

Dispersal and Spread

The hemlock woolly adelgid spreads mainly as eggs and crawlers which are transported by wind, birds, deer, and other forest-dwelling mammals (McClure 1990, Cheah et al. 2004, Ward et al. 2004). It can also be moved on infested nursery stock or during logging and recreational activities (McClure 1995, Gibbs 2002, Ouellette 2002). Roads, hiking areas and riparian areas have all been implicated in the long-distance spread of the adelgid by humans and birds (Koch et al. 2006). Recent evidence suggests that the current rate of spread is between 8-16 km per year (Evans and Gregoire 2007). As of 2011, 47 % of the native range of eastern hemlock is infested with HWA (A. Steketee, USDA Forest Service, personal communication).

Eastern Hemlock

Eastern hemlock, *Tsuga canadensis* (L.) Carriére, is an extremely shade-tolerant, monoecious, slow-growing, late successional conifer with a dense, evergreen crown and that strongly influences its environment and other species (Ward and McCormick 1982, Godman and Lancaster 1990, Evans et al. 1996, Quimby 1996, Evans 2000). Eastern hemlock has a conical crown with horizontal-to-pendulous branches (Ruth 1974) and 2-ranked needles (Dirr 1998). It exhibits relatively low branch shedding (Kenefic and Seymour 2000), and retains its needles for an average of three years (Barnes and Wagner 1981).

Eastern hemlock is a relatively long-lived species with a life span of over 800 years (Godman and Lancaster 1990). Seed production usually begins when trees are 20-30 years of age (Ruth 1974). It is a frequent and abundant cone producer (Crow 1996), with good crops being produced every 2 to 3 years (Frothingham 1915, Ruth 1974).

Native Range

Eastern hemlock is widely distributed in North America from Nova Scotia across southern Ontario to northern Minnesota, and south to Alabama along the Appalachian Mountains (Brisbin 1970, Godman and Lancaster 1990, Quimby 1996). Hemlock generally grows in areas with cool humid climates (Godman and Lancaster 1990, McWilliams and Schmidt 2000). Annual precipitation ranges from 74 cm to more than 127 cm across the range of eastern hemlock (McWilliams and Schmidt 2000). It grows at elevations from sea level to 730 m in the northeastern and northern areas, from 300 to 910 m on the Allegheny Plateau and from 610 to 2036 m in the southern part of its range (Hough 1960, Eyre 1980, Godman and Lancaster 1990).

Growth and Associated Species

Hemlock can occur in pure stands (Eyre 1980), or mixed with other species. On favorable sites, it usually forms a climax position (Brisbin 1970) while on sites with rich in nutrients, it can be out competed by hardwoods (Kotar 1996). In pure stands, undergrowth vegetation can be sparse (Eyre 1980) due to intraspecific allelopathy (Ward and McCormick 1982) and to the dense evergreen crown of hemlock which intercepts both light and precipitation. Because of this dense canopy in hemlock stands the microclimate is cooler than under hardwoods (Tubbs 1996). This distinct microclimate provides an important habitat for a wide variety of wildlife (Evans 2000). In the northeastern United States 96 bird and 47 mammal species have been found to be associated with eastern hemlock forests (Yamasaki et al. 2000). This includes 23 species of small mammals, 14 species of wide ranging carnivores, 10 species of amphibians, and 7 species of reptiles (Degraaf et al. 1992). Hemlock forests can also be a critical factor in the support of native brook trout populations, where it maintains cool stream temperatures and stabilizes stream flows (Evans et al. 1996, Quimby 1996). Eastern hemlock fills a unique ecohydrological role because it transpires throughout the year and it provides stable water fluxes within a watershed and high water flux patterns in the spring, reducing nutrient loss and decreasing watershed discharges (Ford and Vose 2007).

Chemical Evaluation

Imidacloprid Neonicotinoids represent the most effective insecticide for controlling piercing sucking insects such as aphids, leafhoppers, planthoppers, thrips, fleas and some coleopteran (e.g. leaf beetles) and selected species of lepidopteran and dipteran pests (Mullins 1993, Tomizawa and Casida 2005, Elbert et al. 2008). Neonicotinoids comprise seven different commercially available products: acetamiprid, clothianidin, dinotefuran, imidacloprid, nitenpyram, thiacloprid and thiamethoxam (Tomizawa and Casida 2005, Elbert et al. 2008) and have been the only new class of insecticides developed since the 1970s (Tomizawa and Casida 2005). The name neonicotinoids was adopted to show the structural and mode of action differences from nicotine and nicotine-related compounds (Matsuda et al. 2009). The factors that contribute to the success of this class of insecticides is their plant systemicity (Elbert et al. 2008), and mode of action, which offers no cross-resistance to other conventional long-established insecticides (Jeschke and Nauen 2008).

Imidacloprid, 1-[(6-chloro-3-pyridinyl)methyl]-*N*-nitro-2-imidazolidinimine, is a broad spectrum neonicotinoid insecticide with low to moderate mammalian toxicity (Mullins 1993), high insecticidal potency (Lansdell and Millar 2000, Tomizawa and Casida 2005), and a good environmental and toxicological profile (Silcox 2002). As a result it has become one of the world's most widely used insecticides (Silcox 2002, Jeschke and Nauen 2008). It is both a

systemic and contact insecticide (Mullins 1993) and has become the preferred pesticide for controlling HWA (Smith and Lewis 2005, Eisenback et al. 2008).

Imidacloprid was first synthesized by Nihon Bayer Agrochem in 1985 (Elbert et al. 1998), and first registered in the United States under the tradename Merit® in 1994 (Silcox 2002). It is classified in toxicity classes II (moderately toxic) and III (slightly toxic) by the Environmental Protection Agency. Imidacloprid is sold under a variety of tradenames: Admire®, Advantage®, Gaucho®, Premise®, and Touchstone®. In 2006, imidacloprid came off patent and became generic (Jeschke and Nauen 2008).

Mode of Action

Imidacloprid has a mode of action similar to that of the botanical product nicotine, functioning as a fast-acting insect neurotoxicant (Schroeder and Flattum 1984) that binds to the post-synaptic nicotinic acetylcholine receptors (nAChRs) of the insects' central nervous system (Jeschke and Nauen 2008). Imidacloprid mimics the action of acetylcholine, and thereby heightens, then blocks the firing of the postsynaptic receptors with increasing doses (Schroeder and Flattum 1984, Felsot 2001). Acetylcholine is the major excitatory neurotransmitter of insect's central nervous system (Lansdell and Millar 2000, Tomizawa and Casida 2003); it binds and then is degraded by the inactivating enzyme acetylcholine esterase (Breer and Sattelle 1987). Because imidacloprid is not removed by acetylcholine esterase, it causes substantial disorder within the nervous system leading to tremors, paralysis and in most cases death (Mullins 1993, Smith and Krischik 1999). Toxicity studies have demonstrated that this insecticide is neither carcinogenic nor teratogenic (Mullins 1993).

Translocation in Plants

Translocation experiments from a number of vascular plants (e.g. corn, cotton, and eggplant) have shown that imidacloprid has good translaminar movement (Elbert et al. 2008) and excellent xylem mobility to shoots and leaves and poor phloem mobility to storage organs, roots and fruits; as a result the highest residues are expected in the older leaf portions of the plant (Sur and Stork 2003). The systemic properties of imidacloprid are a function of its physical properties, mainly its high water solubility (Cox et al. 1997, Oi 1999), low n-octanol/water partition coefficient ($K_{o/w}$) (Nemeth-Konda et al. 2002), low vapor pressure (Lagalante and Greenbacker 2007) and dissociation coefficients (K_d) (Sur and Stork 2003).

Metabolism in Plants

Most of the imidacloprid administered to plants is metabolized, with little of the parent compound imidacloprid remaining (Nauen et al. 1998). The metabolites formed are dependent

on the method of application (Nauen et al. 1998) and the species of plant treated (Sur and Stork 2003). Because of the variety of functional groups present in the imidacloprid molecule, it undergoes degradation by a number of different pathways and creates a number of different metabolites (Tomizawa and Casida 2003). Metabolites vary in their biological activity against certain insect species (Nauen et al. 1998, Nauen et al. 1999, Nauen et al. 2001), with some being active against mammalians and deactivated against insects (Tomizawa et al. 2000).

Metabolism in Soil

Under field application conditions only a small amount of the applied pesticide ever reaches the target; the majority is released into the soil, and must be degraded photochemically, abiotically and biologically (Wamhoff and Schneider 1999). For Imidacloprid, sorption-desorption processes along with photodegradation and hydrolysis determine the distribution and fate in the soil-water environment (Cox et al. 1997). Imidacloprid undergoes various physio-chemical processes when applied to the soil (Nemeth-Konda et al. 2002).

As with the metabolism in plants, imidacloprid and its metabolites are affected by application method and soil properties (e.g. pH and clay content), with different metabolites having different sorption rates based on the amount of organic carbon present (Cox et al. 1997) and the length of time in the soil (Oi 1999). Insecticides that are sorbed to soil particles are not bioavailable, so they first must be desorbed from the soil into solution to be bioavailable (Koskinen et al. 2001). Desorption for imidacloprid and its metabolites has been shown to be hysteric (Cox et al. 1997). Hysteric desorption indicates that there is a higher desorption coefficient than sorption for some of the metabolites (Oi 1999), making it more difficult for these molecules to reach the target (tree roots) (Cox et al. 1997). The half-life of imidacloprid in soil is between 48-190 days, depending on the formulation, application rate and amount of ground cover (Scholz and Spiteller 1992). In neutral or acidic water, imidacloprid is stable and slowly hydrolyzed (Liu et al. 2006).

Potential non-target effects of imidacloprid

Due to the systemic properties of imidacloprid the potential for non-target effects on arthropods may be expected. Imidacloprid is highly mobile and depending on treatment (e.g. drench, soil application) movement to other non-target plants in the treatment area should be expected. As mentioned in the section on mode of action imidacloprid has high insecticidal potency and works through activation of the nicotinic acetylcholine receptors, causing paralysis and eventually death. Therefore any arthropods (beneficial or otherwise) that ingest plant material (e.g. foliage, sap, seeds, and propolis) or are exposed to a foliar application in a treatment area are likely to demonstrate lethal or sub-lethal effects

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